Quantum in Singapore: Opportunities for collaboration to drive mutual growth

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1. Executive Summary

Singapore is investing to position itself as an important hub in the global ecosystem and supply chain for quantum technologies. Both the UK and Singapore have recognised the potential of quantum technologies to revolutionise computing, communications, and sensing. Since 2002, Singapore has invested heavily in quantum research and development relative to the nation's size, committing around S$700m (~£400m) to date.

The FCDO is seeking to assess whether Singapore represents a valuable partner for collaboration in quantum technology research and development, and to identify the specific areas where such collaboration would be most impactful.

Our analysis of Singapore's quantum ecosystem reveals three potential opportunities for collaboration that align with the UK's Quantum Missions and offer good prospects for mutual growth: quantum middleware, quantum sensing for defence, and quantum networking.

Quantum middleware

Development progress in the software to integrate quantum and classical computers ("quantum middleware") is lagging and could be a bottleneck to realising the value of quantum computers in the near term. The UK and Singapore have both announced early-stage investment plans to accelerate the development of quantum middleware.

Recommendations:

- Form institutional partnerships between the UK's NQCC (National Quantum Computing Centre) and Singapore's NQCH (National Quantum Computing Hub) to identify opportunities for collaboration.
- Establish innovation acceleration initiatives to leverage Singapore's HQCC (Hybrid Quantum Classical Computing) programme to advance UK quantum development.
- Arrange middleware-focused trade delegation to support high-value commercial opportunity.
- Potential benefit to the UK: accelerate the UK's public and commercial R&D (Research and Development) programmes to deliver Quantum Mission 1 and grow exports from the UK to Singapore for UK businesses developing quantum middleware.

Quantum sensing for defence

Singapore's National Quantum Programme includes an ambition to identify and adapt quantum sensors for defence. The development of new quantum sensors has the potential to provide new operational capability for defence and security, particularly in Position, Navigation and Timing (PNT (Position, Navigation, and Timing)). Despite its ambitions, it is an area of relative weakness for Singapore, whereas the UK's Quantum Mission for PNT (Position, Navigation, and Timing) is a world-leading initiative supported by academic and commercial institutions. Due to the sensitive nature of this technology, care will need to be taken to ensure that partnerships account for security concerns and potential export controls.

Recommendations:

- Strengthen bilateral research and security ties on quantum sensing technologies.
- Promote companies within the UK developing quantum sensors for defence applications, particularly for PNT (Position, Navigation, and Timing) Potential benefit to the UK: accelerate the UK's defence R&D (Research and Development) programmes to deliver Quantum Mission 4 and 5, diversify customer base for UK companies developing quantum sensing technology through the identification of new application areas in Singapore, and attract investment into UK Quantum start-ups from Singaporean VCs.

Quantum networking

Singapore is a global leader in quantum networking (especially space-based QKD (Quantum Key Distribution)) and has established links with UK institutions. This capability and local infrastructure may be invaluable to the UK, which seeks to deploy "the world's most advanced quantum network at scale, pioneering the future quantum internet" as part of Quantum Mission 2.

Recommendations:

- Identify partnerships which support the quantum networking mission.
- Potential benefit to the UK: accelerate the UK's R&D (Research and Development) programmes and access infrastructure to deliver Quantum Mission 2.

2. Introduction

2.1. Background and purpose

The commercialisation of quantum technologies promises advances in computing, sensing and communications, with national programmes across the world supporting the efforts of start-ups and research organisations to deploy lab-based demonstrations into the real world. However, significant uncertainty remains on which market sectors will benefit the most, and what high-value, validated use cases exist where quantum solutions will make a real difference.

Both the UK and Singapore governments have published national strategies promoting quantum technologies and are investing heavily in research and development. The FCDO wishes to understand where Singapore is investing, what the ecosystem's strengths and weaknesses are, and whether there are any clear opportunities for collaboration between the two nations.

This report aims to provide:

- An overview of the quantum ecosystem in Singapore – including hotspots of activity, key technologies, major players, policies, initiatives and investments.
- Potential opportunities for collaboration between the UK and Singapore – research and development of a specific quantum technology for use in a specific industry.
- Recommendations to the FCDO to stimulate collaboration in these technology application areas.

2.2. Methodology

Data and insight has been gathered from three main types of sources:

- Desk-based research: reviewed national strategies, relevant government policies, key organisations and their initiatives, investment landscape, international partnerships.
- Cambridge Consultants (CC) quantum technology experts: leveraged CC's deep knowledge of quantum technologies and the UK ecosystem to build hypotheses.
- Interviews: completed 10 interviews with representation of a wide range of main players across the Singapore ecosystem, from government and academia to the private sector. Through these discussions, we gathered insight from key opinion leaders in the quantum space and tested our hypotheses. See table below for the list of interviewees. Contact details have been provided to the FCDO for interviewees who have given explicit consent for us to do so.

#	Organisation	Interviewee name	Role	Contact details provided to FCDO?
1	NQO (National Quantum Office)	Evon Tan	Deputy Director	Yes

#	Organisation	Interviewee name	Role	Contact details provided to FCDO?
2	Duke NUS (National University of Singapore)	Enrico Petretto, Cynthia Duan Bo	Director of CCB	Yes
3	Speqtral	Robert Bedington, Joanne Liao	Co-founder and CTO	Yes
4	SG Innovate	Hsien-Hui Tong	Executive Director, Investments	Yes
5	CQT (Centre for Quantum Technologies), NUS (National University of Singapore)	Prof Yvonne Gao	Principal Investigator	Yes
6	Entropica Labs	Ewan Munro	CTO	Yes
7	Fraunhofer Singapore	Michael Kasper	CEO	Yes
8	[Confidential VC (Venture Capital)]	–	Partner	No
9	CQT (Centre for Quantum Technologies), Oxford University	Artur Ekert	Founding Director of CQT (Centre for Quantum Technologies)	Yes
10	Singapore EDB (Economic Development Board)	Kenneth Ler	Regional Director, Europe	Yes

3. Singapore’s quantum landscape

3.1. Summary

Singapore is investing to position itself as an important hub in the global quantum technology ecosystem and supply chain.

- Singapore has committed to invest S$300mn (~£170mn) in quantum through its National Quantum Strategy (NQS (National Quantum Strategy)), building on over S$400mn it has already invested since 2002.
- The NQS (National Quantum Strategy) is coordinated through national-level programmes, targeting quantum computing, processors, sensors, semiconductors and quantum-safe networks.

- The National Quantum Strategy's future will be shaped by the next RIE (Research, Innovation and Enterprise) 2030 plan which is currently under development, expected to be revealed later this year. Singapore's research, innovation, and enterprise (RIE (Research, Innovation and Enterprise)) plan is a recurring 5-year roadmap that aims to to expand research and development in key areas, strengthening Singapore's innovation capabilities.

Recognising its resource limitations, Singapore is making strategic investments in specific technologies that have the potential to be world-class.

- Singapore has achieved significant momentum in quantum communications through targeted infrastructure investments and strategic partnerships.
- The National Quantum Computing Hub (NQCH (National Quantum Computing Hub)) emphasises middleware and hybrid quantum-classical integration rather than competing in hardware development.
- The National Quantum Sensor Programme (NQSP (National Quantum Sensor Programme)) represents a promising emerging capability with potential for breakthrough applications.

Despite talent pool constraints, Singapore achieves research excellence through its focus on institutional excellence, targeted development, and international partnerships.

- The quality of research at Singapore's Centre for Quantum Technologies is on par with that of major international centres, including UK's Cambridge and Oxford.
- There is a global shortage of qualified quantum researchers. Singapore has recognised this issue and aims to address its needs through its National Quantum Scholarships Scheme (NQSS (National Quantum Scholarships Scheme)).
- Strong existing international partnerships, including those with the UK, Germany and France, amplify Singapore's limited talent pool through regular knowledge exchange.

More details on the key players and quantum technology focus areas in Singapore's quantum ecosystem can be found in Appendices.

We are already seeing these technologies emerging from research into national security implementations and early commercial development.

> National security applications demonstrate the clearest pathway from research to deployment.

Singapore supports commercialisation through government co-investment, successfully attracting global venture capital.

- Singapore's S$440mn (~£250mn) Startup SG Equity scheme enables direct government co-investment alongside private investors in deep tech start-ups.
- Singapore's approach successfully attracts international venture capital, evidenced by its capture of 58% of ASEAN (Association of Southeast Asian Nations) venture funding.

- With portfolios that now include several of Singapore's quantum start-ups, global investors are clearly signalling their interest in Singapore's quantum ecosystem.

However, to fully realise its quantum ambitions Singapore needs international partnerships.

- International partnership agreements establish foundational frameworks that give Singapore access to major quantum programmes and infrastructure.
- Academic collaborations address Singapore's scale and capability constraints through mutually beneficial international partnerships.
- Commercial partnerships provide immediate access to quantum hardware and platforms that Singapore cannot currently develop independently.

3.2. Singapore's quantum ecosystem

Singapore's quantum ecosystem has coverage across the quantum technology development pipeline, from fundamental research through to early commercial applications. The ecosystem connects government, academia, start-ups and international partners. There is clear evidence of research collaborations in the public sector, with strong ties to government organisations and alignment to national initiatives. Additionally, public organisations actively support local start-ups, fostering B2B collaborations between these start-ups and international enterprises.

Singapore is also investing to position itself as an important hub in the global quantum technology ecosystem and supply chain. Singapore has established its quantum technology ecosystem through strategic investment and coordinated national programmes, with the intent of positioning itself as Southeast Asia's leading quantum hub and a critical regional partner for global quantum initiatives.

3.3. National Quantum Strategy

Singapore launched its National Quantum Strategy (NQS (National Quantum Strategy)) in May 2024, allocating nearly S$300mn (~£170mn) over five years under the Research, Innovation and Enterprise (RIE (Research, Innovation and Enterprise)) 2025 plan. Building on over S$400mn that Singapore had already invested in quantum research since 2002, the NQS (National Quantum Strategy)'s future will be shaped by the next RIE (Research, Innovation and Enterprise) 2030 plan, which is currently under development and expected to be revealed later this year.

Whilst modest compared to major global programmes (UK £3bn, Germany €5bn, China US$15bn), this strategically focused investment sets Singapore up to become an important hub in the global quantum ecosystem.

The NQS (National Quantum Strategy) aims to create a quantum ecosystem that attracts international investment, develops local talent, and positions Singapore as the preferred regional partner for global quantum initiatives. To achieve this Singapore is pursuing targeted capabilities through coordinated government programmes, extensive international partnerships, and private sector engagement.

3.4. National Quantum Office

The coordination and development of specific strategies and activities to progress the development of these research areas, including R&D (Research and Development), investment, and implementation of solutions and prototypes, are primarily done through the five programmes listed below. These programmes are supported by the Quantum Engineering Programme (QEP (Quantum Engineering Programme)), and are all overseen by the National Quantum Office (NQO (National Quantum Office)) – see Appendix B and A, respectively.

- National Quantum-Safe Network (NQSN (National Quantum-Safe Network)): The NQSN (National Quantum-Safe Network) tests and deploys quantum-safe communication technologies, positioning Singapore as a trusted partner for international quantum communication networks and as a regional testbed for quantum security.
- National Quantum Processor Initiative (NQPI (National Quantum Processor Initiative)): The NQPI (National Quantum Processor Initiative) develops domestic capabilities in quantum processor design, reducing Singapore's dependence on foreign quantum processors and establishing local expertise that attracts international partnerships.
- National Quantum Sensor Programme (NQSP (National Quantum Sensor Programme)): The NQSP (National Quantum Sensor Programme) coordinates research in quantum sensing applications including those with defence applications, creating capabilities that serve both national security and commercial opportunities.
- National Quantum Computing Hub (NQCH (National Quantum Computing Hub)): The NQCH (National Quantum Computing Hub) builds expertise in quantum computing applications through industry-academia partnerships, serving as Singapore's gateway for international quantum computing collaborations and middleware development.
- National Quantum Federated Foundry (NQFF (National Quantum Federated Foundry)): The NQFF (National Quantum Federated Foundry) provides supporting infrastructure and advanced fabrication capabilities, establishing Singapore as a manufacturing and development node in the global quantum supply chain.

3.5. Strategic investments

Recognising its resource limitations, Singapore is making strategic investments in specific technologies that have the potential to be world-class. Singapore has established quantum technology capabilities spanning computing, communications, sensing, and enabling technologies. However, with clear understanding of its resource constraints, Singapore prioritises selective competitiveness in three specific domains where it can leverage unique advantages rather than competing broadly with global quantum leaders.

- Quantum Communications: Singapore has achieved momentum in quantum communications through targeted infrastructure investments and strategic partnerships. The National Quantum-Safe Network (NQSN (National Quantum-Safe Network)) has progressed from testbed trials to nationwide deployment through NQSN+ (National Quantum-Safe Network Plus), with SpeQtral and network operators Singtel and SPTel building interoperable quantum-safe networks. Speqtral has partnered with Luxembourg-based satellite operator SES to develop satellite-based Quantum Key Distribution linking Asia and Europe, which will integrate with Singapore's existing fibre network to create quantum-secure connectivity.
- Quantum Computing: The NQCH (National Quantum Computing Hub) emphasises middleware and hybrid quantum-classical integration rather than competing in hardware development. The NQCH (National Quantum Computing Hub) recently launched the S$24.5mn Hybrid Quantum Classical Computing (HQCC (Hybrid Quantum Classical Computing) 1.0) initiative. The initiative aims to advance middleware, algorithms, and applications whilst accessing cutting-edge hardware through international partnerships. These partnerships include companies like Quantinuum, a UK-US company with its European headquarters in Cambridge, UK.
- Quantum Sensing: The NQSP (National Quantum Sensor Programme) represents an emerging initiative within the Singaporean quantum ecosystem. The programme aims to coordinate research efforts and end-user engagement in Position, Navigation & Timing (PNT (Position, Navigation, and Timing)), remote sensing and biomedical applications. However, projects are at an early stage of development relative to other quantum technology development in Singapore. There is limited evidence of commercialisation (e.g. through field trials) and only one spin-out from the CQT (Centre for Quantum Technologies) currently developing quantum sensors into products (Atomionics).

3.6. Research excellence

Despite talent pool constraints, Singapore achieves research excellence through its focus on institutional excellence, targeted development, and international partnerships. Globally, the quantum sector is challenged with a shortage of qualified researchers. Singapore faces these same constraints. However, it has achieved world-class research output by concentrating resources in established institutions with defined specialisations, implementing targeted talent development schemes, and addressing retention challenges by leveraging international partnerships.

The Centre for Quantum Technologies (CQT (Centre for Quantum Technologies)) exemplifies Singapore's approach to quantum research. It operates with 260+ staff and students across Singapore's national universities NUS (National University of Singapore), NTU (Nanyang Technological University), SUTD (Singapore University of Technology and Design), and the A*STAR (Agency for Science, Technology and Research) agency. Listed among the world's leading quantum research centres, CQT (Centre for Quantum Technologies) produces world-class research across quantum computation, communication, and sensing. CQT (Centre for Quantum Technologies) researchers collaborate with leading institutions including the University of Oxford, France's National Centre for Scientific Research (CNRS (Centre National de la Recherche Scientifique)), and the Technical University of Munich (TUM (Technical University of Munich)), whilst participating in international initiatives like the Global Network of Optical Magnetometers (GNOME) to search for Exotic physics.

The National Quantum Scholarships Scheme (NQSS (National Quantum Scholarships Scheme)) addresses talent limitations by offering up to 100 PhD and 100 Master-level scholarships to students of all nationalities over the next five years. The scheme targets graduates who will contribute skills and expertise to Singapore's quantum industry and research institutions, addressing workforce development needs. Since launching in 2024, it has supported 14 PhD students from five countries at CQT (Centre for Quantum Technologies).

See Appendix B and C for more details on Singapore's R&D (Research and Development) and academic institutions.

International partnerships amplify Singapore's limited talent pool through regular knowledge exchange. These include academic collaborations with German institutions such as the Dieter Schwarz Foundation, UK partnerships like the CQT (Centre for Quantum Technologies)-Oxford Research Fellowship and the NUS (National University of Singapore)-Strathclyde connection in satellite communications, and French initiatives like MajuLab. Industry partnerships with companies like Quantinuum and AWS (Amazon Web Services) also contribute to talent development.

3.7. Early commercial development

Singapore has established a quantum start-up ecosystem demonstrating technology transfer from research institutions to commercial ventures. Technologies are emerging primarily through government procurement and research markets rather than broad commercial adoption, with secure communication applications showing the most concrete implementation progress.

Secure communication applications are Singapore's clearest demonstrations of progress from research to deployment. SpeQtral's satellite-based quantum key distribution and Singapore's National Quantum-Safe Network exemplify the transition of quantum technologies from research to real-world deployment. SpeQtral secured US$13.9mn in mixed private and government-linked funding to address national security needs, while companies like S-Fifteen Instruments are already supplying quantum security products for immediate use within government infrastructure. These initiatives demonstrate how quantum technology is beginning to move from the lab into operational environments, particularly in government-controlled settings.

Singapore's quantum start-ups remain focused on early-stage innovation. Major funding rounds reflect growing global investor interest in practical quantum technologies. Horizon Quantum Computing raised US$21.3mn from international VCs including Tencent to develop accessible quantum programming tools. Similarly, Entropica Labs secured US$6.5mn from investors such as State Farm Ventures to advance fault-tolerant quantum computing software. Both companies remain focused on early-stage innovation, with limited commercial traction beyond initial funding — inline the nascent state of the global quantum software sector.

Hardware ventures including AQSolotl and Anyon Technologies illustrate Singapore's diversity in quantum technology development but remain largely pre-commercial. Recent efforts have centred on piloting systems at the National Quantum Computing Hub rather than commercial product deployment. This underscores the critical, industry-wide validation phase required before quantum hardware can transition from laboratory prototypes to commercial products.

For for more details on Singapore's start-ups and quantum technology see Appendix D and F, respectively.

3.8. Government co-investment

Singapore supports commercialisation through government co-investment, successfully attracting global venture capital. Singapore accounts for 58% of ASEAN (Association of Southeast Asian Nations) venture funding, supported by a national investment architecture that operates through specialised entities blending government backing with private capital. This model creates pathways for both domestic innovation and international market access.

Government co-investment reduces risk perception for venture capital firms. Singapore's S$440mn (~£250mn) Startup SG Equity scheme enables direct government co- investment alongside private investors in deep tech startups. Administered by EnterpriseSG and EDB (Economic Development Board), it targets Singapore-based ventures, including quantum startups. This co-investment model signals state commitment and company potential whilst de-risking investments for venture capital firms.

Singapore's approach successfully attracts international venture capital, evidenced by its capture of 58% of ASEAN (Association of Southeast Asian Nations) venture funding. This model of government co-investment positions Singapore companies as lower-risk, higher-credibility investments for global venture capital firms, whilst ensuring continued technology transition from research to commercial applications.

With portfolios that now include several of Singapore's quantum startups, global investors such as Tencent, Start Farm Ventures, TIS Japan, and CerraCap Ventures are clearly signaling their interest in Singapore quantum ecosystem.

EDBI (Economic Development Board Investment) has been selected to manage a fund that invests in other investment funds. SEEDS Capital and SGInnovate have been chosen to help invest in startups alongside other investors. See Appendix E for more details on investment entities and venture capital firms.

3.9. International partnerships

However, to fully realise its quantum ambitions Singapore needs international partnerships. Singapore's quantum ecosystem relies on strategic international partnerships to access global expertise whilst building domestic capabilities. This collaborative approach addresses practical limitations — Singapore cannot independently develop comprehensive quantum capabilities. Strategic partnerships offer efficient pathways to quantum leadership in targeted domains.

National-level partnerships establish foundational frameworks that give Singapore access to major quantum programmes and infrastructure. The France-Singapore quantum MoU (Memorandum of Understanding) provides access to French research networks through CNRS (Centre National de la Recherche Scientifique), building on the MajuLab collaboration. Finland's trilateral partnership of VTT (VTT Technical Research Centre of Finland) Technical Research Centre, IQM (IQM Quantum Computers) Quantum Computers, and CSC (CSC - IT Center for Science) IT Centre focuses on include access to the LUMI supercomputer. The £10mn UK-Singapore SpeQtre satellite mission, led by RAL Space and Speqtral, demonstrates government-to-government collaboration, whereas the broader UK-Singapore Strategic Partnership provides a framework for quantum collaboration alongside other advanced technologies.

Academic collaborations address Singapore's scale and capability constraints through mutual international partnerships rather than purely domestic development. These collaborations take shape through joint research facilities and academic exchange programmes with world-leading quantum institutions. The France-Singapore MajuLab joint research centre exemplifies deep institutional collaboration, whilst the CQT (Centre for Quantum Technologies)-Oxford Research Fellowship creates two-way knowledge exchange, building on foundational ties established through CQT (Centre for Quantum Technologies) founding director Artur Ekert's Oxford connections. And the University of Strathclyde partnership supports Singapore's satellite QKD (Quantum Key Distribution) capabilities through the SpeQtre mission.

Commercial partnerships provide immediate access to quantum hardware and platforms that Singapore cannot currently develop independently. Singapore has negotiated such access through partnerships with established quantum hardware providers and emerging technology companies. Collaborations with Quantinuum, IBM (International Business Machines), and Rigetti give Singapore's researchers and companies access to state-of-the-art quantum systems, whilst HSBC participates in the MAS (Monetary Authority of Singapore) quantum security initiative. Meanwhile, domestic companies including Horizon Quantum Computing, Entropica Labs, and SpeQtral develop specialised capabilities within the global ecosystem, supported by partnerships with international players like Xanadu and SES Luxembourg.

These partnerships offer Singapore access to quantum research networks, specialised facilities, and collaborative funding opportunities. Ultimately, the success of these partnerships depend on effective knowledge transfer and coordination, especially in the face of shifting geopolitical dynamics and intensifying global competition.

See Appendix C for more details on Singapore's academic institutions.

4. Opportunities for collaboration and investment

Based on our analysis of Singapore's current quantum R&D (Research and Development) programmes, we have identified three main opportunities for collaboration with the UK.

We advise focusing on three specific opportunity areas that align well with the UK's Quantum Missions, and which have the potential for significant commercial growth: quantum middleware, quantum sensing for Defence, and quantum networking. The table below summarises these opportunities, highlighting the potential benefit to the UK, our assessment of how impactful they could be, and our recommended actions for FCDO:

Opportunity areas	Potential benefit to the UK	Impact	Recommendations
Quantum Middleware	Accelerate the UK's public and commercial R&D (Research and Development) programmes to deliver the UK's Quantum Mission 1. Grow exports from the UK to Singapore for UK businesses developing quantum middleware	High	Form institutional partnerships between the UK's NQCC (National Quantum Computing Centre) and Singapore's NQCH (National Quantum Computing Hub) to identify opportunities for collaboration. Establish innovation acceleration initiatives to leverage Singapore's HQCC (Hybrid Quantum Classical Computing) programme to advance UK quantum development. Arrange a middleware-focused trade delegation to support high-value commercial opportunity
Quantum Sensing for Defence	Accelerate the UK's defence R&D (Research and Development) programmes to deliver the UK's Quantum Missions 4 and 5. Diversify the customer base for UK companies developing quantum sensing technology through identification of new application areas in Singapore. Quantum startups in UK might be attractive to Singaporean VCs	Medium-High	Strengthen bilateral research and security ties on quantum sensing technologies. Promote companies in the UK developing quantum sensors for defence applications, particularly for PNT (Position, Navigation, and Timing).
Quantum Networking	Accelerate the UK's R&D (Research and Development) programmes and access infrastructure to deliver Quantum Mission 2	Medium-Low	Identify partnerships which support the quantum networking mission

UK efforts focus on five quantum missions coordinated by the DSIT (Department for Science, Innovation and Technology)'s Office for Quantum

The UK's National Quantum Programme was launched in 2014 and was renewed with the new National Quantum Strategy published in 2023. The current government has recommitted to the UK's ambitious plans by declaring Quantum Technologies as one of six frontier technologies for the Digital and Technologies industrial sector. The UK has committed to spend £670mn "to drive the development and adoption of quantum computers". This is used as an example of the most impactful interventions by UK government for industry in the recently published Modern Industrial Strategy.

The current strategy focuses the UK's efforts on five Quantum Missions, which aim to develop a range of quantum technologies over the next 5-10 years. The opportunities we have identified align well with these missions:

Mission	Objective	Recommendation alignment
Mission 1	"By 2035, there will be accessible, UK-based quantum computers capable of running 1 trillion operations and supporting applications that provide benefits well in excess of classical supercomputers across key sectors of the economy."	Aligns with the Quantum Middleware opportunity.
Mission 2	"By 2035, the UK will have deployed the world's most advanced quantum network at scale, pioneering the future quantum internet".	Aligns with the Quantum Networking opportunity.
Mission 3	"By 2030, every NHS Trust will benefit from quantum sensing-enabled solutions, helping those with chronic illness live healthier, longer lives through early diagnosis and treatment."	Limited research and development activity in Singapore suggests that there are few opportunities to boost collaboration in this area at this time.
Mission 4	"By 2030, quantum navigation systems, including clocks, will be deployed on aircraft, providing next-generation accuracy for resilience that is independent of satellite signals."	Aligns with the Quantum Sensing for Defence opportunity.
Mission 5	"By 2030, mobile, networked quantum sensors will have unlocked new situational awareness capabilities, exploited across critical infrastructure in the transport, telecoms, energy, and defence sectors."	Aligns with the Quantum Sensing for Defence opportunity.

4.1. Quantum middleware

Potential benefit to the UK

- Accelerate the UK's public and commercial R&D (Research and Development) programmes to deliver Quantum Mission 1.
- Grow exports from the UK to Singapore for UK businesses developing quantum middleware.

4.1.1. Context

Progress in quantum middleware development is lagging and could be a bottleneck to realising the value of quantum computers in the near term.

- Roadmaps published by leading global quantum computing companies like IBM (International Business Machines) show credible routes for continued hardware development.
- Software to integrate quantum and classical computers ("quantum middleware") is required to scale capability but quantum middleware R&D (Research and Development) features less prominently on these roadmaps.

The UK and Singapore have announced significant investments in quantum computing, including early-stage plans to accelerate the development of quantum middleware.

- The UK government has identified quantum computing as an example of a high-value technology in its Modern Industrial Strategy, having committed £670mn over the next 10 years to fund the advancement of quantum computing development and adoption.
- The UK's National Quantum Computing Centre (NQCC (National Quantum Computing Centre)) has a mission to address the key engineering challenges involved in scaling quantum computers, supported by the UK-based Quantum Software Lab which aims to accelerate the development of quantum computing software.
- Singapore's National Quantum Computing Hub (NQCH (National Quantum Computing Hub)) has established a Hybrid Quantum-Classical Computing (HQCC (Hybrid Quantum Classical Computing)) initiative, with a funding of S$25mn (~£14mn) from Singapore's National Research Foundation (NRF (National Research Foundation)).

4.1.2. Recommended actions for FCDO

- Form institutional partnerships between the UK's NQCC (National Quantum Computing Centre) and Singapore's NQCH (National Quantum Computing Hub) to identify opportunities for collaboration.
- Establish innovation acceleration initiatives to leverage Singapore's HQCC (Hybrid Quantum Classical Computing) programme for advancing UK quantum development.
- Arrange a middleware-focused trade delegation to support this potentially high-value commercial opportunity.

4.1.3. Additional commentary

- Quantum middleware is a relatively immature part of the technology stack, and could potentially be a high-growth area
- It is a strong focus area for both the UK and Singapore, which increases likelihood that stakeholders will engage.
- UK quantum middleware companies are likely to be already engaged with stakeholders in Singapore.

Quantum computing value increasingly lies in middleware and integration capabilities rather than hardware alone, a situation well-recognised by both Singapore and the UK. Quantum middleware represents the critical enabling layer between quantum hardware and applications, essential for practical quantum computing deployment.

Hardware is continuing to advance across the quantum computing stack, closely following the roadmaps established by companies like IBM (International Business Machines), and is demonstrating steady improvements in quantum computing. However, middleware development has not kept pace with hardware advances. Quantum middleware remains at a very early stage of development globally, with many fundamental challenges yet to be addressed, creating a critical gap between quantum processors and practical applications.

The quantum computing landscape is shifting towards comprehensive software and integration solutions, with hardware becoming just one component of practical quantum systems.

Middleware and software development represent a critical bottleneck for quantum computing deployment. Developers need accessible tools to leverage quantum resources without deep quantum physics expertise or knowledge of what the quantum processor is actually doing. Error correction, quantum-classical workflow orchestration, and execution optimisation require software solutions that can bridge the gap between quantum hardware capabilities and real-world applications.

Both the UK and Singapore recognise this as the pathway to near-term quantum utility Singapore's HQCC (Hybrid Quantum Classical Computing) initiative exemplifies this focus beyond hardware development. Whilst initiatives like the National Quantum Processor Initiative (NQPI (National Quantum Processor Initiative)) address fundamental hardware challenges, the HQCC (Hybrid Quantum Classical Computing) recognises that practical quantum advantage requires sophisticated middleware, software tools, and seamless classical-quantum integration. Likewise in the UK, NQCC (National Quantum Computing Centre), in partnership with the Quantum Software Lab, works to accelerate development of quantum computing software and applications, including through the development of quantum middleware.

4.1.4. Singapore's quantum middleware capabilities

Singapore is building its quantum middleware capabilities through national initiatives and specialised start-ups to enable practical hybrid quantum-classical computing. Singapore recognises middleware as essential for practical quantum computing deployment.

The National Quantum Office (NQO (National Quantum Office)) orchestrates middleware development through the National Quantum Computing Hub (NQCH (National Quantum Computing Hub)) which serves as the primary platform for quantum computing and its applications across finance, drug discovery, and logistics through industry-academia partnerships and international collaborations.

Within the NQCH (National Quantum Computing Hub), the Hybrid Quantum Classical Computing (HQCC (Hybrid Quantum Classical Computing) 1.0) initiative specifically targets middleware development, focusing on:

- Seamless quantum-HPC (High-Performance Computing) integration
- Middleware and software tool development
- Talent pipeline creation for hybrid systems
- Near-term quantum advantage through hybrid approaches

Launched in March 2025, the HQCC (Hybrid Quantum Classical Computing) 1.0 initiative remains largely in the planning phase with limited demonstrated results to date. The initiative has been allocated S$25mn in funding by the National Research Foundation (NRF (National Research Foundation)). This amount is believed to be separate from the National Quantum Strategy fund (S$300mn).

The National Quantum Processor Initiative (NQPI (National Quantum Processor Initiative)) and National Quantum Federated Foundry (NQFF (National Quantum Federated Foundry)) provide the hardware foundation and fabrication capabilities that middleware solutions will interface with.

Singapore’s quantum software start-ups provide complementary efforts Horizon Quantum Computing offers a platform enabling classical developers to leverage quantum resources, and Entropica Labs develops fault-tolerant tools that provide quantum-classical bridging capabilities.

However, reflecting the broader quantum software market, Singapore’s start-ups remain early-stage ventures with limited commercial deployment.

4.1.5. The UK’s complementary quantum strategy and middleware capabilities

The UK’s Quantum Mission 1 sets an ambitious target: “By 2035, there will be accessible, UK-based quantum computers capable of running 1 trillion operations and supporting applications that provide benefits well in excess of classical supercomputers across key sectors of the economy”.

Government strategy and funding commitment

The UK’s Modern Industrial Strategy named Quantum as one of six priority frontier technologies in the dedicated digital and technologies sector plan. The government has announced £670mn funding for quantum computing, with 10-year backing for the National Quantum Computing Centre (NQCC (National Quantum Computing Centre)) — marking it amongst the first R&D (Research and Development) institutions to receive a 10-year funding settlement. Over £500mn is committed over the next five years, representing a step change in both the scale and type of support for the sector.

Key UK institutions driving progress

- National Quantum Computing Centre: The NQCC (National Quantum Computing Centre)'s mission is to address the key engineering challenges involved in scaling quantum computers, translate UK research into innovation, and support the growth of the UK's quantum computing ecosystem. The NQCC (National Quantum Computing Centre)'s efforts include engagement with industry to identify valuable quantum applications through the SparQ programme.
- Quantum Software Lab: In partnership with the NQCC (National Quantum Computing Centre), the Quantum Software Lab serves as the UK's central hub for quantum software development. Its primary mission is to accelerate the development of quantum computing software and applications by identifying, developing, and validating real-world use cases where quantum computing can deliver benefits beyond the reach of classical computers.

Supporting ecosystem

The NQCC (National Quantum Computing Centre)'s efforts are also supported by a growing number of UK companies specialising in middleware solutions. For example, Riverlane is developing its DeltaFlow Quantum Error Correction Stack to enable scalable quantum computing through real- time error correction, whilst Nu Quantum creates Quantum Networking Units (QNUs (Quantum Networking Units)) to interconnect multiple quantum processors for modular, distributed quantum systems.

4.1.6. Opportunities

Singapore presents near-term middleware opportunities for the UK, particularly in error correction and distributed computing solutions.

Singapore's S$25mn+ HQCC (Hybrid Quantum Classical Computing) 1.0 programme creates demand for sophisticated middleware that aligns with UK capabilities.

Singapore's Hybrid Quantum Classical Computing initiative aims to integrate quantum computers with high- performance computing resources through sophisticated middleware and software tools. Singapore's quantum ambition and the nascent HQCC (Hybrid Quantum Classical Computing) initiative presents the UK with an ideal opportunity.

The HQCC (Hybrid Quantum Classical Computing) 1.0 initiative mirrors similar efforts in the UK through the Quantum Software Lab, creating natural opportunities for collaborative development partnerships between the UK and Singapore.

Opportunities in error correction and distributed quantum computing represent market entry points with limited local competition

We have identified an emerging need in distributed quantum capabilities and an area of opportunity in error correction, with only Entropica Labs being active in this area in Singapore. This early-stage development environment presents significant commercial opportunities for UK companies with proven middleware solutions to establish market position before the field matures.

The UK's market leaders are well-positioned to contribute to these areas

Nu Quantum leads in quantum networking and distributed quantum computing solutions, whilst Riverlane specialises in quantum error correction middleware and operating systems. Both companies could accelerate UK-Singapore's HQCC (Hybrid Quantum Classical Computing) development through strategic partnerships that build local capabilities whilst leveraging proven UK expertise.

Targeted engagements and trade missions can increase and strengthen the connections between Singapore-UK quantum ecosystems to accelerate mutual growth

Strategic initiatives can leverage complementary strengths between Singapore's HQCC (Hybrid Quantum Classical Computing) programme and the UK's quantum industry to create meaningful collaboration opportunities. These actions should emphasise mutual benefit, leveraging Singapore's strategic position in Asia and the UK's established quantum research base.

Recommendation 1: Form institutional partnerships between the UK's NQCC (National Quantum Computing Centre) and Singapore's NQCH (National Quantum Computing Hub) can align programmes to identify opportunities for collaboration at an early stage.

These collaborations could focus on software development and quantum error correction, where both centres have complementary expertise. A structured visit by Quantum Software Lab to Singapore's Centre for Quantum Technology would enable knowledge transfer on hybrid system architectures, with joint workshops identifying specific collaboration opportunities.

Recommendation 2: Establish innovation acceleration initiatives to leverage Singapore's HQCC (Hybrid Quantum Classical Computing) programme for advancing UK quantum development.

Singapore's focus on near-term quantum advantage through hybrid approaches offers valuable insights for UK researchers, whilst the UK's deeper quantum software ecosystem can enhance Singapore's middleware capabilities. Secondments between institutions within Singapore and the UK (e.g. NQCC (National Quantum Computing Centre), CQT (Centre for Quantum Technologies), UK universities) would stimulate technology development and help avoid incompatibilities between UK and Singaporean quantum middleware solutions.

Recommendation 3: Arrange a middleware-focused trade delegation to support this potentially high-value commercial opportunity.

Singapore's HQCC (Hybrid Quantum Classical Computing) initiative requires sophisticated middleware solutions that align with UK company capabilities. A targeted trade mission bringing together Singapore's quantum computing stakeholders with UK middleware specialists like Riverlane could highlight commercial opportunities whilst demonstrating Singapore's commitment to practical quantum deployment.

4.2. Quantum sensing for Defence

Potential benefit to the UK

- Accelerate the UK's defence R&D (Research and Development) programmes to deliver Quantum Mission 4 and 5.
- Diversify customer base for UK companies developing quantum sensing technology through identification of new application areas in Singapore, avoid misalignment of R&D (Research and Development) activities.
- Attract investment into UK Quantum start-ups from Singaporean VCs.

4.2.1. Context

Singapore's National Quantum Programme includes an ambition to identify and adapt quantum sensors for defence.

> Quantum sensing applications identified by the National Quantum Sensing Programme as focus areas include defence use cases. Public information suggests that these efforts are relatively immature.

The development of new quantum sensors has the potential to provide new operational capability for defence and security, particularly in Position, Navigation and Timing (PNT (Position, Navigation, and Timing)).

> High-quality PNT (Position, Navigation, and Timing) underpins most military operations and is often provided by global navigation satellite systems (GNSS) like GPS (Global Positioning System). Disruption to GNSS-based PNT (Position, Navigation, and Timing) signals through jamming is becoming an increasing threat. Many global initiatives aim to develop quantum-enabled PNT (Position, Navigation, and Timing) solutions which improve upon existing products, e.g. through increased resilience to disruption of GNSS.

The UK's Quantum Mission for PNT (Position, Navigation, and Timing) is a world-leading initiative supported by academic and commercial institutions.

Sustained investment by government organisations like Dstl (Defence Science and Technolgy) has resulted in high TRL (Technology Readiness Level) demonstrations of quantum sensors for PNT (Position, Navigation, and Timing) applications. Longstanding strategic partnership between the UK and Singapore provides a framework for sharing sensitive technologies.

4.2.3. Recommended actions for FCDO

- Strengthen bilateral research and security ties on quantum sensing technologies.
- Promote companies within the UK developing quantum sensors for defence applications, particularly for PNT (Position, Navigation, and Timing).

More detail provided in Recommendations.

4.2.4. Additional commentary

- An area of strength for the UK and relative weakness for Singapore, despite its ambitions.
- High-risk, high-reward area for the UK due to the sensitivity, export controls and challenges associated with promoting collaboration in defence.
- Expect good commercial opportunities if hurdles associated with the industry sector can be overcome, opportunities which UK companies may not be aware of today.

4.2.5. Quantum sensing R&D (Research and Development) in Singapore

The government's National Quantum Strategy (announced in 2024, S$300M) outlines a vertically integrated plan—from fundamental research to device fabrication and end-use deployment in national priorities, such as defence, secure communications and navigation. However, published demonstrations of quantum sensors outside of laboratory settings are limited, with Atomionics representing the only start-up in Singapore developing quantum sensors.

The Singapore government supports quantum sensor development through the National Quantum Sensor Programme (NQSP (National Quantum Sensor Programme)): A major national initiative coordinated by the National Quantum Office (NQO (National Quantum Office)). For defence purposes, the programme aims has projects developing quantum gravimeters, magnetometers, and portable atomic clocks, which may support advanced quantum-enabled PNT (Position, Navigation, and Timing) systems.

The main focus areas of the NQSP (National Quantum Sensor Programme) are:

- GPS (Global Positioning System)-independent navigation (e.g., for submarines or drones)
- Detection of underground or underwater activity
- Geological survey and infrastructure integrity monitoring

As an example of efforts to explore quantum sensing's defence potential, a virtual roundtable was held in March 2024 as part of the RSIS Military Transformations Event. Speakers from CQT (Centre for Quantum Technologies) (NUS (National University of Singapore)) and

Atomionics discussed how quantum sensors could disrupt future warfare through:

- GPS (Global Positioning System)-independent positioning, navigation, and timing (PNT (Position, Navigation, and Timing))
- Submarine and underground detection for intelligence, surveillance, and reconnaissance (ISR)

4.2.6. Opportunities for quantum sensing in defence

Quantum sensing offers defence forces new ways to navigate, detect, and coordinate without relying on often vulnerable satellite systems.

In Singapore, technologies like cold-atom interferometry, NV-diamond magnetometry, and quantum clocks are being developed to support GPS (Global Positioning System)-free navigation, magnetic anomaly detection, and secure timekeeping. These developments are part of Singapore's broader effort under the National Quantum Sensor Programme.

- NV- Diamond Magnetometry represents a complementary sensing approach for defence. NV-diamond magnetometers offer sensitive detection of magnetic anomalies and with possible use cases including anti-submarine warfare and coastal perimeter monitoring. These sensors can operate at room temperature and are studied at NUS (National University of Singapore) with funding from QEP (Quantum Engineering Programme).
- Cold-Atom Interferometry (Gravimetry) is being actively developed in Singapore for GPS (Global Positioning System)-independent navigation. This technique could allow submarines, drones, and other defence platforms to maintain accurate positioning even in environments where GPS (Global Positioning System) is unavailable or compromised. Singapore-based startup Atomionics is collaborating with DSO (DSO National Laboratories) National Laboratories and is developing portable cold-atom inertial sensors such as Gravio. These systems could be miniaturised for field deployment, and while the main application is subsurface mapping, they can be used in a military context in the next years.
- Quantum Clocks: In parallel, quantum timing systems based on optical and microwave atomic clocks are being advanced to provide resilient timekeeping for secure communications, radar synchronisation, and precision operations in contested environments.

4.2.7. UK expertise in quantum-enabled sensing and PNT (Position, Navigation, and Timing)

The UK's national strategy aims to actively bridge the needs of research, industry, and defence. Central to this effort is the UK's Quantum Mission 4, a key component of the UK's National Quantum Strategy, which is driving the development of quantum navigation systems—such as cold atom inertial sensors and optical atomic clocks—for resilient operations in GPS (Global Positioning System)-denied environments.

The mission builds on sustained investment in quantum sensing, with a strong focus on quantum-enabled PNT (Position, Navigation, and Timing) technologies, which have resulted in numerous field trials and demonstrations including:

- Airborne Quantum Navigation (Infleqtion/BAE systems/QinetiQ): UK's first airborne trial of a quantum inertial navigation system demonstrated resilient, GPS (Global Positioning System)-free flight .
- Naval Cold-Atom Trials (Aquark Technologies): Royal Navy tested compact cold-atom sensors aboard HMS Pursuer for GPS (Global Positioning System)-denied maritime navigation and PNT (Position, Navigation, and Timing) robustness.
- Dstl (Defence Science and Technolgy) Deployable Atomic Clock: Dstl (Defence Science and Technolgy) unveiled an ultra-precise atomic clock for secure, independent timing in hostile or degraded environments.

Recent UK investments further underscore the country's leadership in quantum-enabled PNT (Position, Navigation, and Timing), including sustained funding through InnovateUK.

Complementing this mission, the Quantum-Enabled PNT (Position, Navigation, and Timing) Hub—a national research centre led by the University of Glasgow—serves as a collaborative engine bringing together academic researchers, commercial developers, and defence stakeholders. It focuses on quantum sensing technologies like gravimetry, inertial navigation, and precision timing.

Beyond quantum technologies, the UK has also identified resilient PNT (Position, Navigation, and Timing) as a key risk for national security (for example, through the publication of the Blackett Review on GNSS-based PNT (Position, Navigation, and Timing)). As a result, DSIT (Department for Science, Innovation and Technology) has established the Office for PNT (Position, Navigation, and Timing), which leads national efforts to strengthen resilience in navigation and timing. Its role includes supporting the development of alternative PNT (Position, Navigation, and Timing) technologies—such as quantum clocks and inertial systems—and reducing reliance on satellite-based systems like GPS (Global Positioning System)

4.2.8. Need for international support

Singapore's ambition to deploy quantum sensing technologies for defence may be difficult to achieve without international support.

Singapore sees quantum sensing as critical for defence applications like navigation in GPS (Global Positioning System)-denied environments and submarine detection. Backed by the S$300mn National Quantum Strategy (EDB (Economic Development Board), 2024) and insights from forums such as RSIS's Quantum Sensing and Future Warfare roundtable (RSIS, 2024), the focus is clear—but domestic capability is still limited. While CQT (Centre for Quantum Technologies) and the National Quantum Sensor Programme lead foundational research, gaps need to be filled to achieve Singapore's ambitions for quantum sensing for defence.

These gaps open the door for collaboration with the UK, whose mature PNT (Position, Navigation, and Timing) ecosystem and defence ties make it a strong partner. Given the UK's status as a world leader in quantum-enabled PNT (Position, Navigation, and Timing), it has developed mature prototypes in cold-atom navigation, compact gravimetry, and deployable atomic clocks. The UK's ability to transition lab-grade systems into field-ready technologies makes it a valuable partner and given there are strong ties in defence between the UK and Singapore, technology transfer should be easily enabled.

Gaps identified in Singapore's quantum sensing for defence ambitions

- Limited breadth of commercial players: The commercial quantum sensing ecosystem in Singapore is limited, with Atomionics as the only company actively developing relevant technology.
- Narrow academic base: CQT (Centre for Quantum Technologies) and the National Quantum Sensor Programme (NQSP (National Quantum Sensor Programme)) are the primary initiatives driving quantum sensing research in Singapore. While CQT (Centre for Quantum Technologies) hosts multiple investigators (spanning NUS (National University of Singapore), NTU (Nanyang Technological University), SUTD (Singapore University of Technology and Design), and A*STAR (Agency for Science, Technology and Research)) working on atomic clocks, gravimetry, and magnetometry — and collaborates with DSO (DSO National Laboratories) on defence-relevant topics — most of this work remains focused on fundamental science.
- Novel operating environment: Due to geographic and geopolitical differences, the needs of Singapore's defence sector may be significantly different from those which may be provided by off-the-shelf quantum sensing products and solutions. Technologies may need to be adapted to make these products attractive for Singapore.
- Lack of scaled field-testing infrastructure: Limited funding for live demonstrations or multi-domain deployment trials may limit the opportunities to test quantum sensors in realistic environments.
- Miniaturisation challenges: Current demonstrations of quantum sensing systems in Singapore are mostly in lab or prototype form, with minimal engineering maturity for field operations.

4.2.9. Challenges

Various challenges are likely to arise when encouraging collaboration in quantum sensing for defence due to the sensitive nature of the technology.

Security considerations and general constraints

Quantum-enabled PNT (Position, Navigation, and Timing) systems can be highly sensitive and subject to export control. Both the UK and Singapore treat such technologies as dual-use or defence-relevant, which means collaboration will require careful navigation of licensing, IP protection, and national security protocols. Secure sharing mechanisms and clear legal frameworks will be essential for bilateral R&D (Research and Development) and deployment.

Another challenge lies in facilitating meaningful engagement between the relevant stakeholders, ensuring that technology developers, end-users, and decision-makers are aligned.

Alignment with UK priorities

While the UK's national missions—particularly Quantum Mission 4—focus on advancing technologies like atomic clocks, atom interferometers, and gravitometers to enhance national resilience and secure infrastructure, the direct relevance of these technologies to Singapore's operational needs is not yet clear. Singapore's specific defence challenges and deployment environments may differ significantly from those targeted by UK programmes, meaning that a straightforward transfer of capability may not be obvious.

This divergence could be an advantage, opening opportunities for customised solutions rather than off-the-shelf adoption. However, it also means collaboration and capability sharing may require careful alignment rather than assuming direct technology transfer.

4.2.10. Opportunities

Quantum sensing capability developed through the UK's National Quantum Programme has the potential to meet Singapore's defence needs.

The UK's capability in quantum sensing is more mature than initiatives within Singapore. By identifying where quantum sensing can be adapted to Singapore's defence challenges, the UK has an opportunity to promote trade and strengthen bilateral R&D (Research and Development) for defence.

Recommendation 4: Strengthen bilateral research and security ties on quantum sensing technologies.

There is no publicly available evidence that programmes on quantum sensing in Singapore and the UK are aligned. Connecting quantum sensing leads in Singapore (MINDEF (Ministry of Defence) and DSO (DSO National Laboratories)) with Dstl (Defence Science and Technolgy) and other UK defence R&D (Research and Development) centres would ensure that R&D (Research and Development) efforts are not duplicated and that organisations developing quantum sensing technology within the UK are aware of the differing needs of Singapore's defence sector.

Recommendation 5: Promote companies within the UK developing quantum sensors for defence applications, particularly for PNT (Position, Navigation, and Timing).

In order to explore trade and market access opportunities, the British High Commission can support targeted engagement by promoting companies within the UK developing quantum sensors for defence applications — ranging from commercial demonstrations and dual-use start-ups to technologies developed by major defence primes. Facilitating trade delegations, industry showcases, or bilateral innovation exchanges can help UK firms gain early visibility in Singapore's defence tech ecosystem, paving the way for R&D (Research and Development) collaborations, access to local testbeds, and future partnerships.

Singapore is organising a defence showcase to match suppliers of emerging technologies (including quantum) from the UK with procurers and technology developers within Singapore's defence sector. We recommend using this opportunity to advertise the UK's quantum sensing programme and identify where further initiatives or competitions could adapt UK technologies to Singaporean needs.

4.3. Quantum networking

Potential benefit to the UK

> Accelerate the UK's R&D (Research and Development) programmes and access infrastructure to deliver Quantum Mission 2.

4.3.1. Context

Singapore is a global leader in quantum networking (especially space-based QKD (Quantum Key Distribution)) and has historic links with UK institutions.

- UK's National Quantum Strategy, Quantum Mission 2 aims to develop new quantum networking technologies by deploying "the world's most advanced quantum network at scale, pioneering the future quantum internet".
- Strong partnerships between the UK and Singapore provide a foundation on which to build deeper collaborations in quantum technologies.
- Creating a quantum network that can distribute quantum information, allowing quantum computers to be networked together, will require new components which are currently at much lower stages of development.
- The core technology underpinning quantum networks is likely to benefit from capability and infrastructure developed through QKD (Quantum Key Distribution) pilots and product lines.

4.3.2. Singapore's leadership in quantum networking

Singapore has established itself as a global leader in quantum networking, particularly in pioneering space-based quantum key distribution (QKD (Quantum Key Distribution)) technologies, through strategic international partnerships, including UK institutions. These collaborations span flagship satellite mission s, university research partnerships, financial sector applications, and broader strategic frameworks for quantum technology development.

SpeQtre satellite mission: RAL Space and Speqtral partnership

The SpeQtre mission is a flagship joint Singapore-UK satellite project led by RAL Space and SpeQtral, backed by £10mn in joint government funding to demonstrate space-based quantum key distribution (QKD (Quantum Key Distribution)). The mission will likely be the first entanglement-based QKD (Quantum Key Distribution) mission launched outside of China, downlinking quantum keys to ground stations in Chilbolton, UK and Singapore.

Financial services QKD (Quantum Key Distribution): HSBC, MAS (Monetary Authority of Singapore) and NQSN (National Quantum-Safe Network)

In 2024, HSBC signed an MoU (Memorandum of Understanding) with Singapore's Monetary Authority (MAS (Monetary Authority of Singapore)) to explore Quantum Key Distribution applications for enhancing cybersecurity in financial services. This collaboration leverages Singapore's National Quantum- Safe Network (NQSN (National Quantum-Safe Network)) infrastructure and includes participation from major Singapore banks (DBS, OCBC, UOB) in testing quantum-safe communication methods.

Quantum-secure communications: Toshiba, Speqtral and ST Engineering Toshiba signed an MoU (Memorandum of Understanding) with SpeQtral and ST Engineering to accelerate quantum-secure communication solutions in Southeast Asia, leveraging Toshiba's world-leading industrial quantum research capabilities. This collaboration builds upon Toshiba's quantum networking expertise developed at its Cambridge Research Laboratory — supported by the UK's National Quantum Programme — to enhance regional quantum-secure communications infrastructure.

University of Strathclyde and NUS (National University of Singapore) collaboration

The National University of Singapore (NUS (National University of Singapore)) signed an MoU (Memorandum of Understanding) with the University of Strathclyde in 2022 focused on satellite quantum communications, facilitating joint experiments using optical ground stations to receive satellite signals. Both institutions participate in the International Network in Space Quantum Technologies, which Strathclyde leads, positioning Singapore within a broader UK-led quantum space network.

UK-Singapore Strategic Partnership

The UK-Singapore Strategic Partnership signed in 2023 establishes co-operation across defence, security, science and technology. The partnership commits to "… promote business co-operation in research and innovation …". This framework provides the foundation for deeper quantum technology collaboration between the two nations.

4.3.3. UK-Singapore partnership opportunities

Alignment with the UK's quantum networking mission could enable deeper collaboration.

Strong partnerships between the UK and Singapore provide a foundation on which to build deeper collaborations in quantum technologies. In particular, within the UK's National Quantum Strategy, Quantum Mission 2 aims to develop new quantum networking technologies by deploying "the world's most advanced quantum network at scale, pioneering the future quantum internet". The mission explicitly calls out the importance of international collaboration, with a stated outcome that the UK wants to work with "at least five other countries to collaborate on underpinning technologies and connectivity with international quantum networks, including through satellite links". The scope of the UK's Quantum networking mission goes beyond QKD (Quantum Key Distribution) technology. Creating a quantum network that can distribute quantum information, allowing quantum computers to be networked together, will require new components which are currently at much lower stages of development. However, the core technology underpinning quantum networks is likely to benefit from capability and infrastructure developed through QKD (Quantum Key Distribution) pilots and product lines.

Currently, the plan to achieve Quantum Mission 2 is not clear. DSIT (Department for Science, Innovation and Technology) is currently carrying out road mapping activities, with more details expected to be announced around August 2025. The current mission lead at DSIT (Department for Science, Innovation and Technology)'s Office for Quantum is Diego Rodriquez Mejias. Academic activity is likely to be led by the UK Integrated Quantum Networks Hub, based at Heriot-Watt University in Edinburgh with Gerald Buller as Director. The hub brings together 13 UK universities, the UK's National Physical Laboratory (NPL (National Physical Laboratory)) and RAL Space, as well as over 40 industrial partners.

Recommendation 6: To benefit from existing partnerships and technology transfer between the UK and Singapore, support should be given to initiatives which align with the objectives of Quantum Mission 2.

Deeper alignment could benefit the UK by: * Gain insights from Singapore's quantum networking activities to provide further clarity and direction for the Quantum Networking mission * Identify relevant infrastructure for the Quantum Networking mission which has been developed, or is in development, in Singapore or through UK-Singapore partnerships (e.g. access to satellite-based entanglement distribution satellites through collaboration with SpeQtral)

5. Summary of recommendations

Based on the findings in this report, we have six main recommendations for the FCDO: 3 in Quantum Middleware, 2 in Quantum Sensing for Defence and 1 in Quantum Networking.

Opportunity area: Quantum Middleware

Accelerate the UK's public and commercial R&D (Research and Development) programmes to deliver Quantum Mission 1. Grow exports from the UK to Singapore for UK businesses developing quantum middleware.

Institutional partnerships for quantum middleware	Form institutional partnerships between the UK's NQCC (National Quantum Computing Centre) and Singapore's NQCH (National Quantum Computing Hub) to identify opportunities for collaboration. BHC (British High Commission) to support visit by Quantum Software Lab to Singapore's Centre for Quantum Technology.
Establish innovation initiatives	Establish innovation acceleration initiatives to leverage Singapore's HQCC (Hybrid Quantum Classical Computing) programme for advancing UK quantum development. Identify mechanisms to establish new secondment schemes, joint research programmes and other innovation initiatives. Should be aligned with opportunities identified through partnerships established between QSL (Quantum Software Laboratory) and HQCC (Hybrid Quantum Classical Computing).

Middleware-focused trade delegation	Arrange a middleware-focused trade delegation to support this potentially high-value commercial opportunity. Facilitate targeted trade missions promoting UK middleware specialists to Singapore's quantum computing stakeholders which could highlight commercial opportunities. Relevant UK companies include Riverlane, Nu Quantum, Qoro Quantum, QuantrolOx and TreQ

Opportunity area: Quantum Sensing for Defence

Accelerate the UK's defence R&D (Research and Development) programmes to deliver Quantum Mission 4 and 5. Diversify customer base for UK companies developing quantum sensing technology through identification of new application areas in Singapore, avoid misalignment of R&D (Research and Development) activities. Attract investment into UK Quantum startups from Singaporean VCs.

Align quantum sensing for defence initiatives	Strengthen bilateral research and security ties on quantum sensing technologies. Support engagement between quantum sensing specialists.
Promote UK PNT (Position, Navigation, and Timing) capabilities	Promote companies within the UK developing quantum sensors for defence applications, particularly for PNT (Position, Navigation, and Timing). Engage with key UK companies and connect them with Singaporean contacts. Relevant UK organisations include Infleqtion, Aquark Technologies, the Quantum-Enabled PNT (Position, Navigation, and Timing) Hub.

Opportunity area: Quantum Networking

Accelerate the UK's R&D (Research and Development) programmes and access infrastructure to deliver Quantum Mission 2.

Identify partnerships which support the quantum networking mission	Identify existing UK-SG partnerships which may support the quantum networking mission. Engage with Quantum Networking Mission leads to highlight the existing UK's international collaborations with Singapore. Identify relevant collaborations and ensure that they help shape the quantum mission programme.

Appendix A: Key government agencies

National Research Foundation (NRF (National Research Foundation))

The National Research Foundation serves as the custodian of Singapore's Research, Innovation and Enterprise (RIE (Research, Innovation and Enterprise)) ecosystem, setting the national direction for R&D (Research and Development) and providing strategic funding for quantum initiatives.

- Established the Centre for Quantum Technologies (CQT (Centre for Quantum Technologies)) in 2007 as a Research Centre of Excellence.

- Provides dedicated funding for the Quantum Engineering Programme (QEP (Quantum Engineering Programme)) with S$121.6mn across two phases.
- Operates within the Prime Minister's Office, positioning quantum initiatives as a national strategic priority.
- Ensures alignment between quantum initiatives and broader national research priorities.

National Quantum Office (NQO (National Quantum Office))

The National Quantum Office functions as the central co-ordinating body, orchestrating quantum research, innovation, and enterprise activities across Singapore, ensuring coherent advancement of the national quantum agenda.

- Co-ordinates numerous national-level programmes including the National Quantum Processor Initiative (NQPI (National Quantum Processor Initiative)) and National Quantum Sensor Programme (NQSP (National Quantum Sensor Programme)).
- Administers the National Quantum Scholarships Scheme (NQSS (National Quantum Scholarships Scheme)) to develop specialised talent.
- Actively fosters public-private partnerships to cultivate a vibrant quantum ecosystem.

Infocomm Media Development Authority (IMDA (Infocomm Media Development Authority))

The Infocomm Media Development Authority serves as Singapore's lead agency for digital infrastructure development and regulation, playing a crucial role in driving the deployment and commercialisation of quantum-safe communications technologies.

- Launched the National Quantum-Safe Network Plus (NQSN+ (National Quantum-Safe Network Plus)) initiative to facilitate commercial deployment of quantum-safe solutions.
- Partners with CQT (Centre for Quantum Technologies) to build quantum-related capabilities and standards in Singapore.
- MoU (Memorandum of Understanding) with South Korea's National Information Society Agency (NIA) on quantum technologies and standardisation efforts.
- Oversees the development of Singapore's first local Standard (Reference Specification) on Quantum Key Distribution Networks.

Ministry of Trade and Industry (MTI (Ministry of Trade and Industry))

The Ministry of Trade and Industry formulates and implements policies to promote Singapore's economic growth and technological advancement, providing overarching governmental supervision for quantum initiatives.

- Provides policy oversight for the National Semiconductor Translation and Innovation Centre (NSTIC (National Semiconductor Translation & Innovation Centre)).
- Supports the S$1bn national semiconductor R&D (Research and Development) fabrication facility announced in Budget 2025.
- Ensures integration of quantum technology strategies with broader economic development goals.

- Aligns quantum initiatives with Singapore's international trade and industry priorities.

Enterprise Singapore

Enterprise Singapore champions enterprise development and growth, supporting quantum technology startups and small-medium enterprises through various funding schemes and industry development initiatives. This agency plays a critical role in enhancing the commercial viability of quantum innovations.

- Administers the Startup SG Equity scheme alongside Singapore's Economic Development Board (EDB (Economic Development Board)) to stimulate investment in quantum technology ventures.
- Serves on the HealthTEC Steering Committee, facilitating health technology innovation.
- Provides grants and support for quantum startups seeking to expand internationally.
- Fosters industry partnerships and knowledge exchange in the quantum domain.

Appendix B: Key R&D (Research and Development) entities

Centre for Quantum Technologies (CQT (Centre for Quantum Technologies))

Established in 2007, CQT (Centre for Quantum Technologies) operates as Singapore's flagship research institution for quantum science and technology, now elevated to a national centre with nodes across multiple institutions including A*STAR (Agency for Science, Technology and Research), NUS (National University of Singapore), NTU (Nanyang Technological University), and SUTD (Singapore University of Technology and Design).

- Serves as the intellectual foundation for the National Quantum Strategy, leading key national initiatives including NQPI (National Quantum Processor Initiative) and NQSN (National Quantum-Safe Network).
- Has generated significant intellectual property and technology transfers, resulting in eight spin-off companies.
- Employs over 260 staff and students conducting fundamental and applied research.
- Engages in extensive international collaborations, including the France- Singapore MajuLab.

Agency for Science, Technology and Research (A*STAR (Agency for Science, Technology and Research))

A*STAR (Agency for Science, Technology and Research) serves as Singapore's lead agency for public sector R&D (Research and Development), contributing to quantum research through several specialised institutes.

- Hosts the NQO (National Quantum Office).
- Hosts the Quantum Innovation Centre (Q.InC (Quantum Innovation Centre)) focusing on quantum software, photonics, sensing, and materials.

- Houses the National Quantum Federated Foundry (NQFF (National Quantum Federated Foundry)) at its Institute of Materials Research and Engineering (IMRE (Institute of Materials Research and Engineering)).
- Conducts quantum computing research through its Institute of High Performance Computing (IHPC (Institute of High-Performance Computing)).
- Collaborates extensively with universities, healthcare institutions, and industry partners.

Quantum Engineering Programme (QEP (Quantum Engineering Programme))

The Quantum Engineering Programme (QEP (Quantum Engineering Programme)) was created in 2018 to establish a competitive quantum engineering research community in Singapore. It focuses on turning research in quantum computing, sensing, and communications into commercially viable quantum applications and products.

The QEP (Quantum Engineering Programme) is hosted by the National University of Singapore (NUS (National University of Singapore)) The NRF (National Research Foundation) has invested a total of S$121.6mn in the QEP (Quantum Engineering Programme).

DSO (DSO National Laboratories) National Laboratories

As Singapore's largest defence R&D (Research and Development) organisation established in 1972, DSO (DSO National Laboratories) National Laboratories employs over 1,800 scientists and engineers.

- Operates an in-house quantum laboratory (established 2019).
- Develops Cold Atom Inertial Sensors (CAIS (Cold Atom Inertial Sensors)) using Rubidium atoms.
- Collaborates with Thales on Superconducting Quantum Interference Filters (SQIF (Superconducting Quantum Interference Filters)).
- Participates in the National Quantum-Safe Network and National Quantum Sensor Programme.
- Focuses on domains offering near-to-mid-term advantages for national security.

Fraunhofer Singapore

Fraunhofer Singapore functions as an application-oriented research organisation bridging academic discoveries and industrial applications, with a focus on quantum security.

- Established a dedicated Competence Centre for Quantum Security.
- Provides vendor-neutral expertise on transitioning to quantum-resistant cryptographic procedures.
- Actively involved in the research and development of the National Quantum-Safe Network (NQSN (National Quantum-Safe Network)).
- Contributes to deployment, standardisation, security testing and certification efforts.

Appendix C: Key academic institutions

National University of Singapore (NUS (National University of Singapore))

Singapore's flagship university, NUS (National University of Singapore) hosts the main node of CQT (Centre for Quantum Technologies) and spearheads the Quantum Engineering Programme (QEP (Quantum Engineering Programme)). The university's research strengths include quantum computing applications for computational biology, integrated photonic quantum technologies, and access to critical fabrication facilities that support the National Quantum Federated Foundry.

- Hosts dedicated quantum research entities including the Quantum Engineering Labs within Electrical and Computer Engineering Department.
- Leads HealthTEC through its Institute for Health Innovation & Technology with potential for quantum integration.
- Facilitates interdisciplinary research across physics, engineering, computing, and medicine.

Nanyang Technological University (NTU (Nanyang Technological University))

NTU (Nanyang Technological University) has positioned itself as a key player in quantum research through the creation of dedicated quantum research platforms and active participation in national quantum initiatives.

- Houses the Quantum Science and Engineering Centre (QSec) with particular emphasis on photonic quantum processors.
- Operates the Nanyang Quantum Hub (NQH) as a collaborative platform for quantum technologies.
- Conducts research in quantum photonics, solid-state materials, cold atoms, and superconducting resonators.
- Engages in health-related quantum applications through its Centre of AI (Artificial Intelligence) in Medicine (C-AIM).

Singapore University of Technology and Design (SUTD (Singapore University of Technology and Design))

SUTD (Singapore University of Technology and Design) contributes to Singapore's quantum ecosystem as a node of CQT (Centre for Quantum Technologies) and a partner in multiple national quantum initiatives. The university's approach leverages its strengths in design and engineering to address quantum technology challenges.

- Participates in the National Quantum Scholarships Scheme (NQSS (National Quantum Scholarships Scheme)) for talent development.
- Faculty research spans quantum information theory, computational nanophotonics, and quantum plasmonics.
- Explores novel 2D semiconductor devices for energy-efficient electronics with quantum applications.

Appendix D: Key start-ups and spin-outs

AngelQ

AngelQ focuses on making quantum computing more accessible by developing qubit-efficient quantum algorithms and user-friendly solutions.

- Founded by Professor Dimitris G. Angelakis, who joined CQT (Centre for Quantum Technologies) in 2009 as a Principal Investigator.
- Develops architecture-agnostic quantum software solutions, including quantum-inspired AI (Artificial Intelligence) and optimisation algorithms.
- Recognised for innovative work, winning 1st Prize in the Canada Quantum Challenge for energy sector applications.
- Maintains strong connections to both CQT (Centre for Quantum Technologies) and NUS (National University of Singapore). [angelquantum.com]

Anyon Technologies

Anyon Technologies specialises in the development of proprietary quantum hardware technologies, particularly focusing on superconducting quantum processors and their integration with classical computing resources.

- Developing high-performance superconducting quantum processors with a scalability roadmap to 100 and 1,000 qubits.
- Collaborating with SDT Inc. on a 20-qubit superconducting quantum system integrated with NVIDIA's Grace Hopper Superchip.
- Founding team includes pioneers from Singapore's A*STAR (Agency for Science, Technology and Research), Caltech, and UC Berkeley.

AQSolotl

AQSolotl delivers practical quantum computing solutions tailored to various industries, focusing on cost-effective and adaptable quantum technology.

- Successfully developed and piloted Chronos-Q, a fully operational Processor Control unit, at Singapore's National Quantum Computing Hub.
- Developing Hyperion-Q, a comprehensive quantum computing platform (expected 2025), and Phoebe-Q, an integrated Quantum AI (Artificial Intelligence) solution (expected 2026).
- Technology emerged from collaborative research between NTU (Nanyang Technological University) Singapore and NUS (National University of Singapore).

Atomionics

Atomionics focuses on quantum gravimetry, developing highly sensitive quantum sensors based on cold atom interferometry for navigation and resource exploration applications.

- Building a portable atomic interferometer with superior sensitivity to commercial gravimeters.
- Potential applications include creating a new GPS (Global Positioning System)-independent positioning system.
- Secured seed funding from Wavemaker Partners, SGInnovate, and Cap Vista.

Entropica Labs

Entropica Labs specialises in developing software tools for fault-tolerant quantum computing, addressing the critical challenge of error correction in quantum systems.

- Founded in Singapore in 2018 as a spin-out from CQT (Centre for Quantum Technologies)
- Secured US$4.7mn in Series A funding led by Wavemaker Partners
- Develops quantum computing and AI (Artificial Intelligence) tools specifically for bioinformatics and genomics applications.

Horizon Quantum Computing

Horizon Quantum Computing develops tools to simplify quantum programming, making quantum computers as accessible and intuitive to program as conventional computers.

- Created Triple Alpha, an integrated development environment for quantum software development.
- Develops tools that automatically transform classical code into quantum- optimised versions.
- Established a hardware testbed at their Singapore headquarters to integrate software with various quantum platforms.
- Founded by staff and alumni of CQT (Centre for Quantum Technologies), with the CEO previously serving as a Principal Investigator.
- Successfully raised funding from SGInnovate and other investors.

pQCee

pQCee specialises in post-quantum cybersecurity, developing solutions to protect data and systems from future quantum computing threats.

- Provides products and solutions to shield against “harvest-now-decrypt- later” attacks.
- Portfolio includes inoQulate (quantum-safe PDF signing, secure email, TLS encryption), QKDLite (quantum-safe key management), and PQ Web3 (quantum-safe blockchain).
- Aims to strengthen Singapore’s business community against future quantum attacks.
- Secured funding in a round co-led by Wavemaker Partners and Seeds Capital.

S-Fifteen Instruments

S-Fifteen Instruments offers a range of quantum security and measurement products.

- Founded in 2017 as a spin-off from CQT (Centre for Quantum Technologies), with co-founders including CQT (Centre for Quantum Technologies) principal investigators.
- Product portfolio includes Quantum Key Distribution (QKD (Quantum Key Distribution)) systems, Quantum Random Number Generators, Photon Pair Sources, and Single Photon Detectors.
- Licensed proprietary technology developed at CQT (Centre for Quantum Technologies).
- Received support from Temasek Foundation Ecosperity.

SpeQtral

SpeQtral leads in quantum communication and security, developing quantum- safe technologies using both satellite and terrestrial fibre networks to protect against quantum computing threats to current encryption.

- Focuses on QKD (Quantum Key Distribution) implemented over both fibre optic cables and via satellite.
- Formed strategic partnerships with SES, Toshiba, and ST Engineering.
- Key participant in Singapore's National Quantum-Safe Network (NQSN (National Quantum-Safe Network)).
- Target markets include governments, corporations, healthcare institutions, and financial organisations.
- Received investment from Xora Innovation. [speqtralquantum.com]

Squareroot8 Technologies (SQRT8 (Squareroot8 Technologies))

Squareroot8 Technologies focuses on quantum cryptography, developing cost- efficient quantum cryptographic devices with minimised energy usage.

- Spin-off from the quantum research lab at NUS (National University of Singapore)'s College of Design and Engineering.
- Designs advanced microelectronic devices for quantum information processing and communication.
- Successfully demonstrated quantum-safe satellite communications using a compact single-board module.
- Developed a lightweight prototype for Post-Quantum Cryptography key exchange using an onboard QRNG (Quantum Random Number Generator) chipset.
- Collaborates with NuSpace, a Singaporean microsatellite company.

Appendix E: Investors

SGInnovate

Singapore's principal deep technology investment catalyst, SGInnovate maintains quantum technologies as a core strategic mandate with the most comprehensive quantum portfolio amongst government-linked investors.

- Portfolio includes: Atomionics, SpeQtral, Horizon Quantum Computing, and Entropica Labs.
- Strategic focus on quantum computing, communications, and sensing domain diversification.
- Partnership with Centre for Quantum Technologies (established 2017).
- Primary participant in Startup SG Equity scheme risk mitigation. [sginnovate.com]

Seeds Capital

Operates under SG Growth Capital, the investment platform of the Singapore Economic Development Board (EDB (Economic Development Board)) and Enterprise Singapore with quantum investments aligned with National Quantum Strategy pillars across software, sensing, and cybersecurity domains.

*Portfolio includes: Entropica Labs, Atomionics, and pQCee. * Merged with EDBI (Economic Development Board Investment) to form SG Growth Capital. * Co-invests through Startup SG Equity framework. * Strategic portfolio co-ordination with Enterprise Singapore's startup mandate.

EDBI (Economic Development Board Investment)

Strategic investment arm of the Economic Development Board focusing on growth-stage technologies with broader deep technology positioning beyond confirmed quantum-specific investments.

- Investment focus on Digital economy, health, hardware, green technologies.
- Portfolio includes River Lane, a UK-based company specialising in quantum error correction.
- Its strategic integration is enhanced through Seeds Capital merger framework (SG Growth Capital).
- Provides growth-stage capital provision to scale quantum ventures.

XORA

Temasek Holdings' early-stage deep science investment platform demonstrating significant commitment to quantum communications technologies with clear strategic defence implications.

- Led SpeQtral's US$8.3mn Series A funding round (November 2021).
- MoU (Memorandum of Understanding) with NTU (Nanyang Technological University) and NUS (National University of Singapore) for a US$75mn joint programme (November 2024).
- Part of Temasek's US$1bn annual deep technology commitment.
- Investment focus on scientific breakthroughs to commercial deployment pathways.

Cap Vista

Investment arm of the Defence Science and Technology Agency (DSTA (Defence Science and Technology Agency)) providing essential defence-focused quantum investment capability with emphasis on strategic security applications.

*Investor in Atomionics' seed round (US$2.5mn, 2021). * Strategically focused on Defence and security technology applications. * Its mission is "To identify, partner and grow early-stage start-ups with dual-use technologies for potential defence and security applications" * Aligns to national security through critical infrastructure and strategic defence positioning.

Tencent Holdings

China's technology conglomerate represents a significant cross-border strategic investment in Singapore's quantum software ecosystem, demonstrating the international recognition of local quantum capabilities despite evolving geopolitical dynamics.

- Led Horizon Quantum Computing's US$18.1mn Series A funding round (2023)
- Strategic positioning in quantum software development tools and compiler technologies
- Broader technology portfolio encompasses quantum computing interests across multiple markets

TIS Inc

Japan's enterprise software specialist provides critical market validation for Singapore's quantum software capabilities, establishing strategic bridges within the Asia-Pacific technology ecosystem

- Strategic investor in Entropica Labs' S$2.6mn seed round (May 2020)
- Focus on enterprise software integration with quantum computing capabilities
- Represents Japan-Singapore technology co-operation in quantum applications

State Farm Ventures

The US insurance giant's venture arm exemplifies sector-specific strategic engagement, recognising quantum computing's transformative potential for actuarial modelling and risk assessment applications.

- Extended Entropica Labs' Series A to US$5.5mn total (September 2024)
- Strategic focus on quantum algorithms for insurance industry applications
- Represents early corporate adoption of quantum technologies in traditional financial services

Singapore quantum startups funding overview

Company	Funding	Lead Investor(s)	Co-Investors
Horizon Quantum Computing	$21.3mn	Tencent, Peak XV Partners, Sequoia Capital India	Pappas Capital, Expeditions Fund, SGInnovate, Abies Ventures, DCVC, Summer Capital
Entropica Labs	$6.5mn	Wavemaker Partners, LIFTT, Elev8.VC (Venture Capital), Entrepreneurs First	SUTD (Singapore University of Technology and Design) Venture Holdings, Seeds Capital, CerraCap Ventures, SGInnovate, Lim Teck Lee, v1.vc, TIS Japan, Creative Destruction Lab (CDL)
SpeQtral	$13.9mn	Xora Innovation, Hello Tomorrow, Space Capital	Shasta Ventures, SGInnovate, Golden Gate Ventures
Atomionics	$500k	Paspalis, Wavemaker Partners, Entrepreneurs First	Apsara Investments, 6th Horizon, 500 Southeast Asia, SGInnovate, CAP Vista, 500 Global
S-Fifteen Instruments		Unfunded, but supported by Temasek Foundation Ecosperity	

Funding details for AQSolotl, AngelQ, Squareroot8 Technologies, Anyon Technologies and pQCee were unavailable at the time of this report.

SOURCES: Crunchbase, Tracxn

Appendix F: Quantum technologies

Quantum computing technologies

Technology area	Current capabilities	Key Singaporean organisations
Quantum Processor Types	Trapped ion systems, Neutral atom arrays, Superconducting qubits, Silicon-based qubits	CQT (Centre for Quantum Technologies), A*STAR (Agency for Science, Technology and Research) IMRE (Institute of Materials Research and Engineering), NUS (National University of Singapore), NTU (Nanyang Technological University)

Technology area	Current capabilities	Key Singaporean organisations
Quantum Software & Algorithms	Development of quantum programming tools, Quantum algorithms for enterprise optimisation, Architecture-agnostic quantum software solutions, Hybrid quantum-classical algorithms	Horizon Quantum Computing, Entropica Labs, AngelQ, A*STAR (Agency for Science, Technology and Research) IHPC (Institute of High-Performance Computing), CQT (Centre for Quantum Technologies), NUS (National University of Singapore) Department of Computer Science
Integration & Control Systems	Cryogenic electronics development, Processor control units for quantum systems, Hybrid quantum-classical computing interfaces, Quantum middleware development	AQSolotl, Anyon Technologies, A*STAR (Agency for Science, Technology and Research) IMRE (Institute of Materials Research and Engineering), NTU (Nanyang Technological University)-NUS (National University of Singapore) partnership
Access & Infrastructure	Cloud access to quantum processors, Quantum-HPC (High-Performance Computing) integration capabilities, Quantum computing testbeds for R&D (Research and Development)	NQCH (National Quantum Computing Hub) (CQT (Centre for Quantum Technologies), A*STAR (Agency for Science, Technology and Research) IHPC (Institute of High-Performance Computing), NSCC (National Supercomputing Centre)), NSCC (National Supercomputing Centre)

Quantum communications technologies

Technology area	Current capabilities	Key Singaporean organisations
Quantum Key Distribution (QKD (Quantum Key Distribution))	Fibre-based QKD (Quantum Key Distribution) systems for terrestrial networks, Satellite-based QKD (Quantum Key Distribution) technology development, Integration of satellite and terrestrial quantum networks, QKD (Quantum Key Distribution) for metropolitan and long-distance secure communication	Speqtral, S-Fifteen Instruments, CQT (Centre for Quantum Technologies) (leading NQSN (National Quantum-Safe Network)), NUS (National University of Singapore) Quantum Communications Lab, Toshiba (partnership with Speqtral), SES (partnership with Speqtral)
Post-Quantum Cryptography (PQC (Post-Quantum Cryptography))	PQC (Post-Quantum Cryptography) implementations for encryption, key management, and digital signatures, Integration of PQC (Post-Quantum Cryptography) with existing security	

Technology area	Current capabilities	Key Singaporean organisations
infrastructure, Hybrid classical-quantum cryptographic solutions, QRNG (Quantum Random Number Generator)-PQC (Post-Quantum Cryptography) modules for satellite communications	PQCEE, Squareroot8 Technologies (SQRT8 (Squareroot8 Technologies)), SEALSQ (establishing operations), Fraunhofer Singapore, NUS (National University of Singapore) Department of ECE	
Quantum Random Number Generators	Photonic quantum random number generators, Hardware-based true random number generation, Integration of QRNGs into security systems	S-Fifteen Instruments, Squareroot8 Technologies, CQT (Centre for Quantum Technologies)
Network Integration	Quantum-safe network technologies and protocols, Interoperability between quantum and classical networks, Testing methodologies for quantum communications	NQSN (National Quantum-Safe Network) ecosystem, Fraunhofer Singapore, ST Engineering, SPTel, IMDA (Infocomm Media Development Authority) (NQSN+ (National Quantum-Safe Network Plus))

Quantum sensing technologies

Technology area	Current capabilities	Key Singaporean organisations
Quantum Bioimaging & Sensing	NV centre diamond sensors for detecting protein- based biomarkers, Quantum hyperspectral IR microscopy for tissue analysis, Nanoscale NV centre magnetic resonance imaging for disease diagnosis	QEP (Quantum Engineering Programme), A*STAR (Agency for Science, Technology and Research) research groups, NUS (National University of Singapore), Duke-NUS (National University of Singapore) Medical School, National Health Innovation Centre (NHIC (National Health Innovation Centre))
Quantum Navigation Systems	Cold atom interferometry for inertial sensing, Development of quantum positioning systems independent of GPS (Global Positioning System), High-precision quantum gyroscopes and accelerometers	Atomionics, A*STAR (Agency for Science, Technology and Research) Quantum Innovation Centre (Q.InC (Quantum Innovation Centre)), DSO (DSO National Laboratories) National Laboratories

Technology area	Current capabilities	Key Singaporean organisations
Quantum Metrology	Quantum-enhanced measurement techniques, High-precision quantum sensing for electric and magnetic fields, Remote sensing capabilities using quantum technologies	National Physical Laboratory (NPL (National Physical Laboratory)), A*STAR (Agency for Science, Technology and Research) IMRE (Institute of Materials Research and Engineering), CQT (Centre for Quantum Technologies) Quantum Sensing group, NTU (Nanyang Technological University) Nanyang Quantum Hub

Supporting technologies and fabrication capabilities

Technology area	Current capabilities	Key Singaporean organisations
Photonic Integrated Circuits	Silicon photonics for quantum applications, Development of low-loss optical waveguides, Integration of photon sources, detectors, and modulators, Fabrication of quantum photonic processors	Squareroot8 Technologies, NTU (Nanyang Technological University) Quantum Science & Engineering Centre (QSec), A*STAR (Agency for Science, Technology and Research) IMRE (Institute of Materials Research and Engineering) (NQFF (National Quantum Federated Foundry)), NUS (National University of Singapore) Quantum Engineering Labs
Microfabrication Processes	Superconducting qubit fabrication, Ion trap electrode structures, Development of site-specific donor placement in silicon, Foundry processes for quantum device fabrication	A*STAR IMRE (Institute of Materials Research and Engineering) (hosts NQFF (National Quantum Federated Foundry)),* A*STAR Institute of Microelectronics (IME (Institute of Microelectronics)), NUS (National University of Singapore)
Advanced Packaging	Integration of heterogeneous quantum components, Thermal management solutions for quantum systems, Chip-to-chip interconnect technologies, Packaging for cryogenic operation	A*STAR (Agency for Science, Technology and Research) IME (Institute of Microelectronics), NSTIC (National Semiconductor Translation & Innovation Centre), Silicon Box
Testing & Characterisation	Cryogenic testing capabilities down to sub-2K temperatures, Wafer-level testing of quantum devices, Advanced quantum device characterisation techniques, Metrology standards for quantum systems	A*STAR (Agency for Science, Technology and Research) IMRE (Institute of Materials Research and Engineering), Tektronix (NQFF (National Quantum Federated Foundry) partnership), AEM, Quantum Design Singapore, Analytical Technologies Singapore

Appendix G: Patent review

Methodology for patent analysis

We utilised Patsnap), a comprehensive patent search and analysis platform, to conduct the searches and analyses of Quantum Technology presented in this report. Our search methodology follows the framework established in 'A portrait of the global patent landscape in quantum technologies' — a 2025 whitepaper published by the European Quantum Industry Consortium (QuIC).

- Search query for quantum computing: (CPC:(G06N10/00 OR G06N10/20 OR G06N10/40 OR G06N10/60 OR G06N10/70 OR G06N10/80) OR TACD:("quantum computing" OR "quantum computer?") AND PRIORITY_COUNTRY:(SG OR WO)) NOT TACD:("quantum crypto*" OR "quantum encrypt*" OR "quantum key?" OR "qkd")
- Search query for quantum sensing: (CPC:(G01R33/0358 OR G01R33/0354 OR G01R33/0356 OR G01R33/326) OR TACD:("atomic vapor" OR "cold cloud" OR "trapped ion?" OR "rydberg atom*" OR ("bose einstein" $SEN condensate) OR (("single spin?") AND ("nmr" OR "quantum dot?")) OR "squid*" OR "charge qubit?" OR "flux qubit?" OR ("squid" OR "sqif") OR "*cold atom*" OR ("nv" OR "nitrogen vacancy" OR "nitrogen defect") $SEN center?) OR "diamond lattice" OR ("diamond" $SEN "nitrogen vacancy")) AND TACD: ("measurement" OR "magetomet*" OR "interferomet*" OR "gyro*" OR "accelero*" OR "radar?" OR "lidar?" OR "ladar?" OR "sensor?" OR "sensing") AND PRIORITY_COUNTRY:(SG OR WO)

Following QuIC's methodology Quantum Communication was split into two search queries:

- Search query for quantum communication (cryptography) (CPC:(H04L9/0852 OR H04L9/0855 OR H04L9/0858) OR TACD:("quantum crypto*" OR "quantum encrypt*" OR "quantum crypt*" OR "quantum key" OR "qkd") AND PRIORITY_COUNTRY:(SG OR WO)) NOT TACD:("post quantum crypt" OR "PQC (Post-Quantum Cryptography)")
- Search query for quantum communication(information networks): CPC:(H04B10/70) OR TACD:("quantum network?" OR "quantum communication?" OR "quantum internet" OR "quantum information network?" OR "quantum teleportation?") AND PRIORITY_COUNTRY:(SG OR WO)

Additional parameters

Searches were further refined using the following filters:

- A simple legal status of either Active or Pending.
- As per QuIC's method we the set the Priority Country to correspond to the selected country / region e.g. Singapore. We also included "WO" (PCT) as the priority country.
- Original Assignee Region was set to the appropriate country / region.

Singapore's quantum patent activity shows concentrated period of growth

Patent activity peaked in 2022 with institutional concentration driving applications

Singapore filed 70 patents across quantum computing, communications and sensing between 2015-2025, with activity concentrated in a three- year period from 2021-2023 accounting for 61% of total applications.

This pattern suggests project-driven rather than sustained innovation cycles, potentially reflecting specific institutional research programmes or funding tranches (i.e. RIE (Research, Innovation and Enterprise) 2025) rather than continuous R&D (Research and Development) momentum.

Academic institutions dominate patent portfolio with quantum communications emphasis

> NUS (National University of Singapore) and NTU (Nanyang Technological University) account for nearly half of applications, with quantum communications leading

Singapore's 70 quantum patents divide across three domains:

- Quantum Communications: 30 patents (43%)
- Quantum Computing: 25 patents (36%)
- Quantum Sensing: 15 patents (21%)

The National University of Singapore (NUS (National University of Singapore)) leads with 21 patents, followed by Nanyang Technological University (NTU (Nanyang Technological University)) with 11 patents. Together, these institutions represent 46% of Singapore's quantum patent output, indicating high concentration within academic research rather than broad commercial innovation.

The emphasis on quantum communications aligns with Singapore's strategic focus areas but also reflects the relative maturity and patentability of QKD (Quantum Key Distribution) and related technologies compared to more experimental quantum computing approaches.

Singapore's global patent share reflects proportional but limited contribution

> Singapore accounts for <1% of global quantum patents

With 70 patents against a global total of 33,540 in quantum computing, communications and sensing (2015-2025), Singapore's contribution represents approximately 1 in every 500 global applications.

The data suggests Singapore has established measurable patent activity but remains a minor contributor to global quantum intellectual property development, consistent with interview insights indicating academic focus over commercial patent strategies.

For comparison, the UK has approximately 486 patents in quantum computing, communications and sensing.

Singapore leads minimal ASEAN (Association of Southeast Asian Nations) quantum patent activity

Regional leadership emerges from limited baseline rather than competitive strength

Within ASEAN (Association of Southeast Asian Nations), Singapore's 70 patents significantly exceed other member states' combined total of 4 patents:

- Malaysia: 2 patents (Universiti Putra Malaysia, MIMOS, Universiti Tun Hussein Onn Malaysia)
- Vietnam: 2 patents (Ho Chi Minh City University of Technology)
- Other ASEAN (Association of Southeast Asian Nations) states: 0 patents identified

Singapore's regional leadership primarily reflects the absence of quantum R&D (Research and Development) infrastructure elsewhere in ASEAN (Association of Southeast Asian Nations) rather than competitive advantage. The concentration of activity within academic institutions (UPM, HCMUT) in other states mirrors Singapore's pattern but at significantly lower scale.